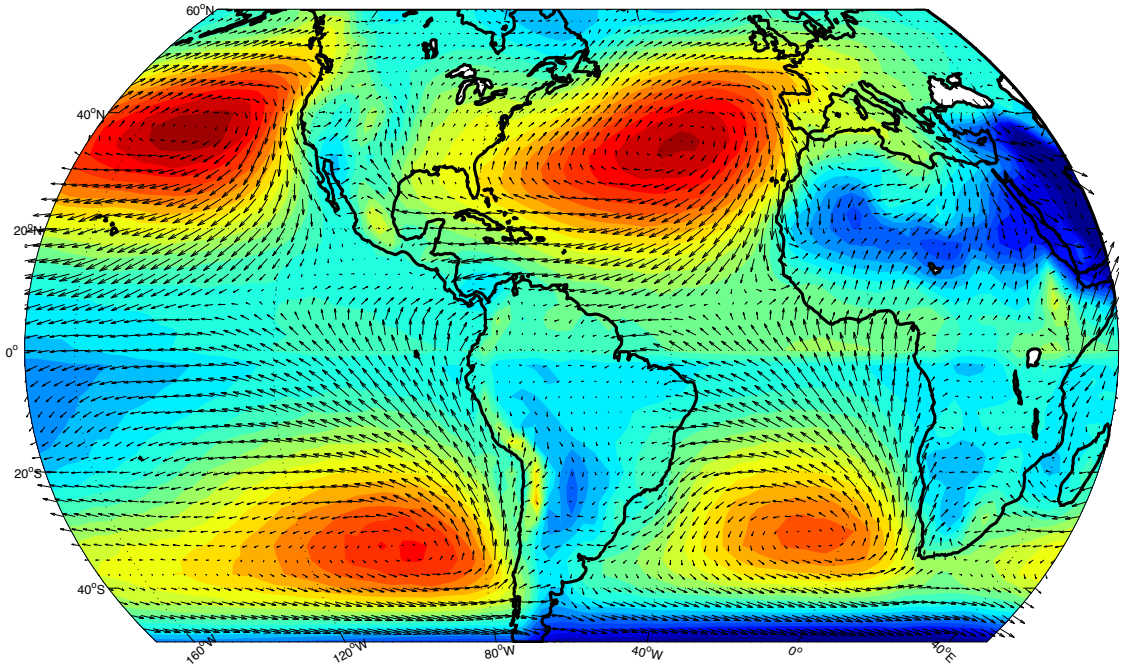
2.11 Ecosystem Research:
Climate Impacts on the California Current System

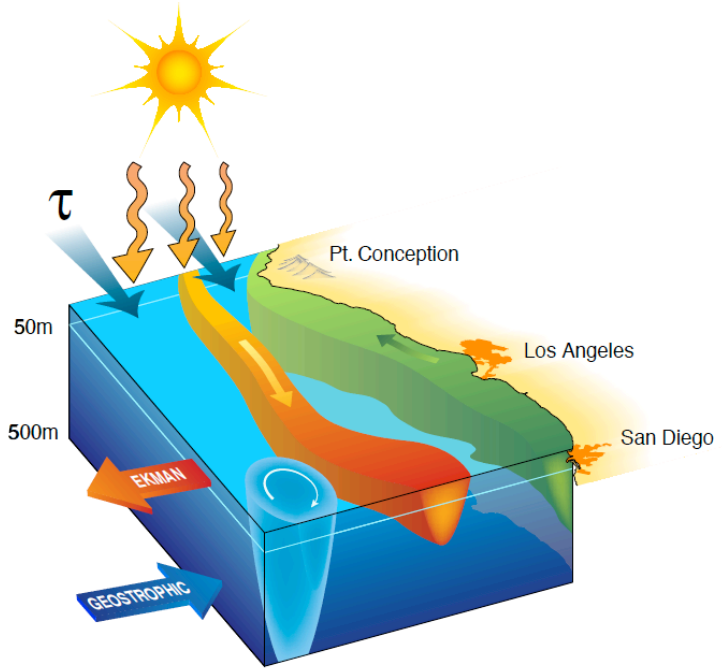
NOAA FISHERIES
Southwest Fisheries Science Center
Environmental Research Division



Q1, Q2, Q4, Q5, Q7, Q8

Scales of Variability in the California Current Ecosystem

- Seasonal
  - Life cycles of marine organisms tied to seasonal processes
  - Trophic interactions ('match-mismatch')
  - Upwelling: timing, intensity, duration
- Interannual-to-Decadal
  - Regional responses to tropical forcing (El Niño)
  - Regime shifts in physical drivers, ecosystem responses
- Climate Change
  - Warming, stratification, source water changes
  - Upwelling intensification
  - Shifts in upwelling phenology



Climate Impacts on the California Current Ecosystem

- Bottom-Up Forcing of the CCLME
  - Species movements & behaviors driven by seasonal productivity
- Applications of Upwelling Research to EBFM
  - The classic Upwelling Index
  - New indices: Interannual variability in upwelling timing, intensity, duration
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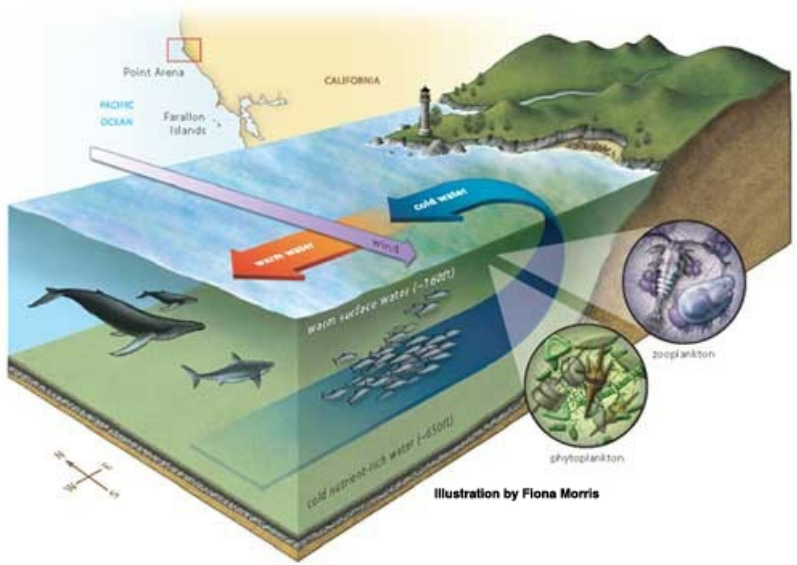
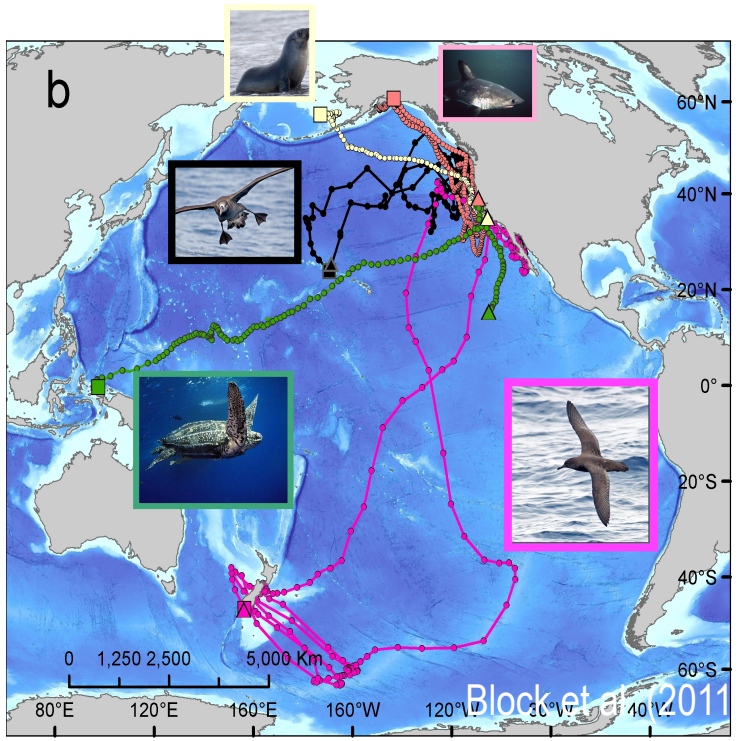
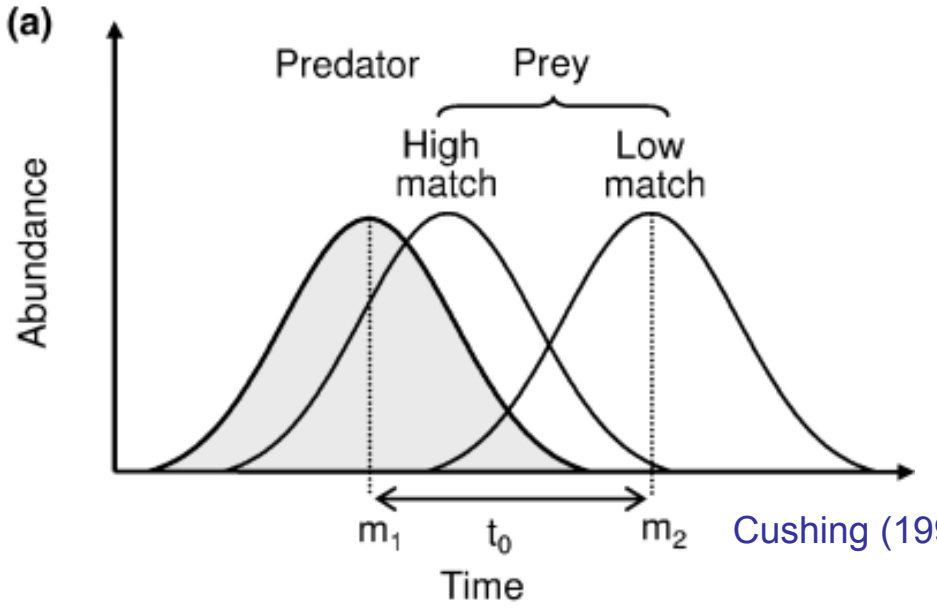
Productivity Driven by Seasonal Coastal Upwelling





- Life cycles of many marine organisms tied to seasonal processes

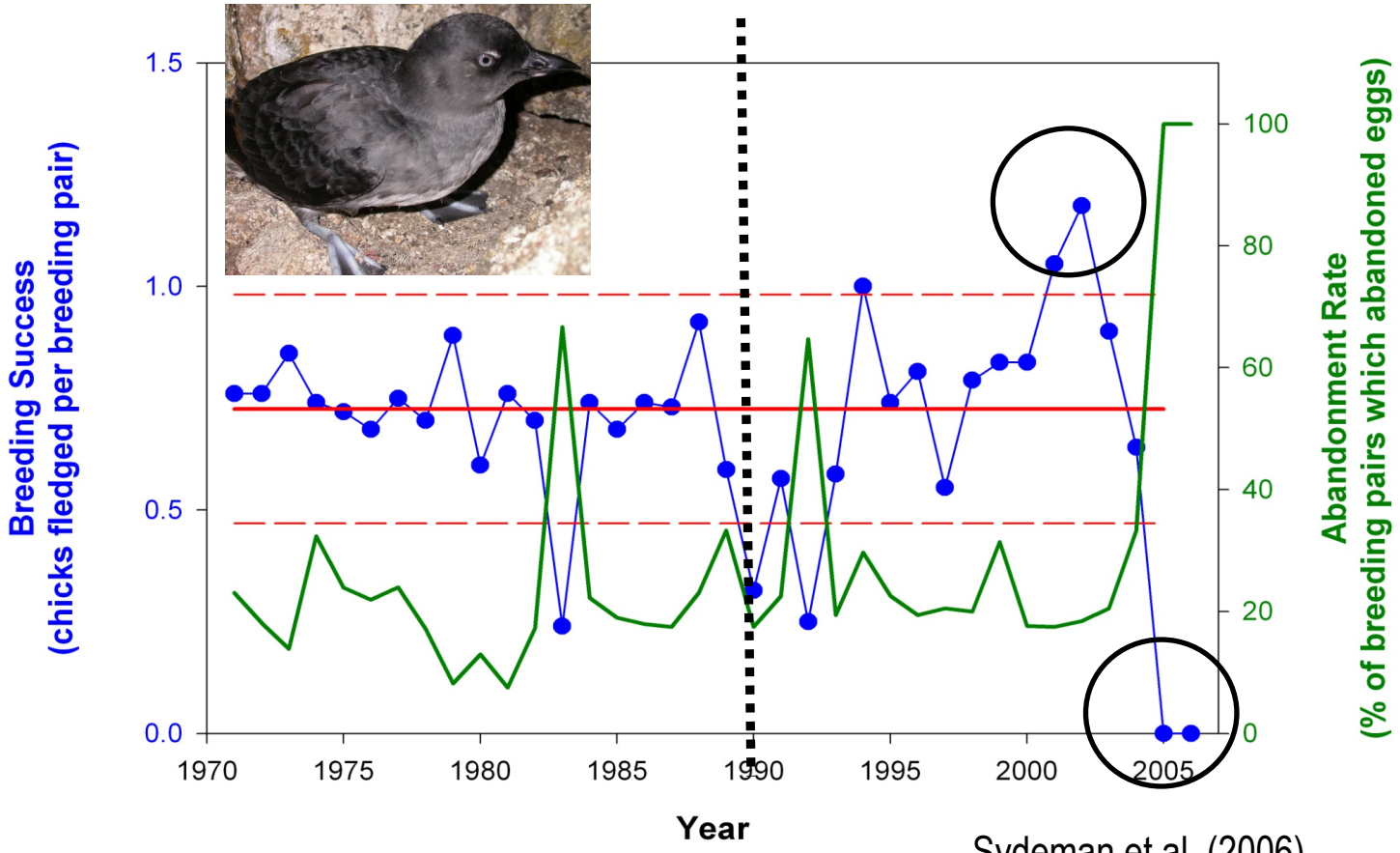
Productivity Driven by Seasonal Coastal Upwelling



Cushing (1990); Durant et al. (2005)

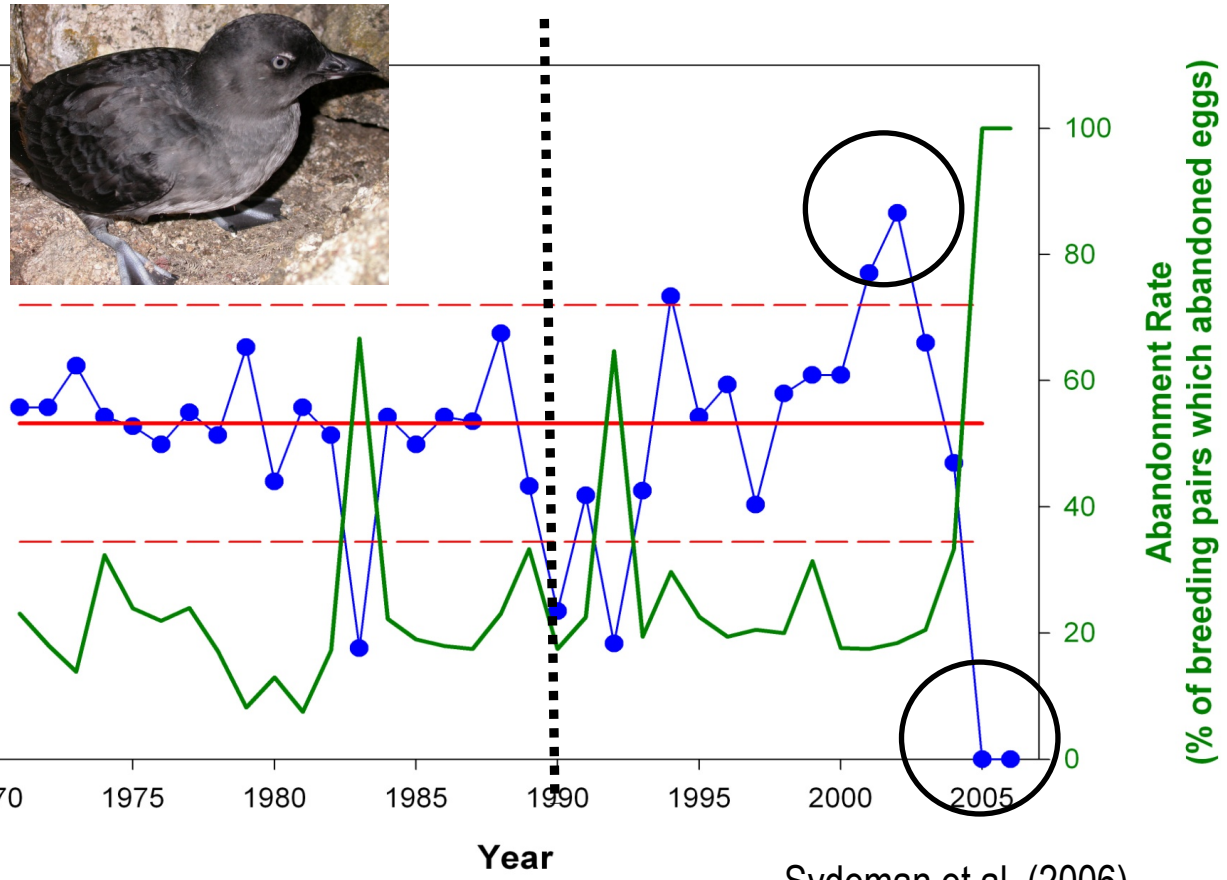
- Life cycles of many marine organisms tied to seasonal processes
- Intensity, duration, timing (phenology) of upwelling strongly influence the ecosystem

Ecosystem Impacts of Coastal Upwelling Variability



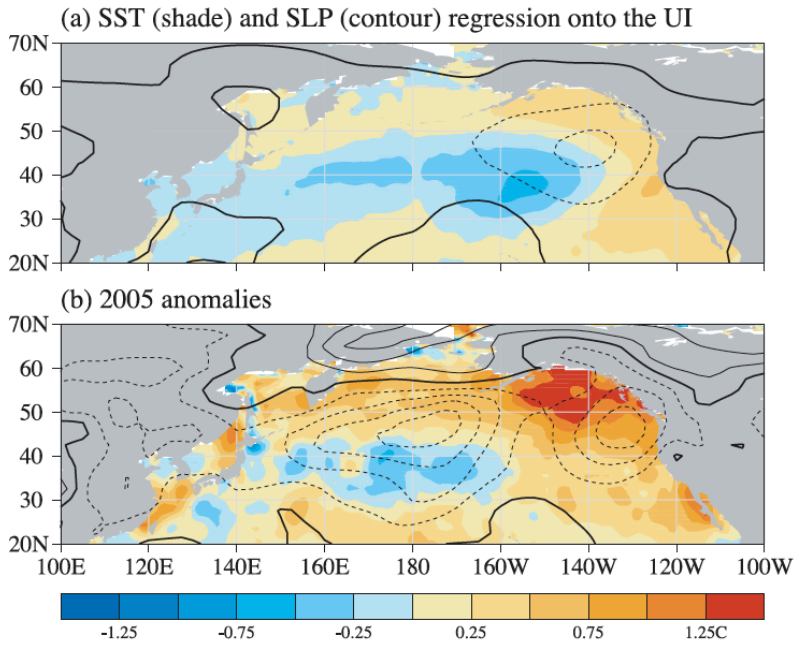
Sydeman et al. (2006)
Schroeder et al. (2009)

Ecosystem Impacts of Coastal Upwelling Variability



Sydeman et al. (2006)
Schroeder et al. (2009)

Reproductive failure of Cassin's Auklet in Central California due to delayed upwelling in 2005



Schwing et al. (2006)

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UPWELLING INDEX: THE WORKHORSE OF FISHERIES OCEANOGRAPHY

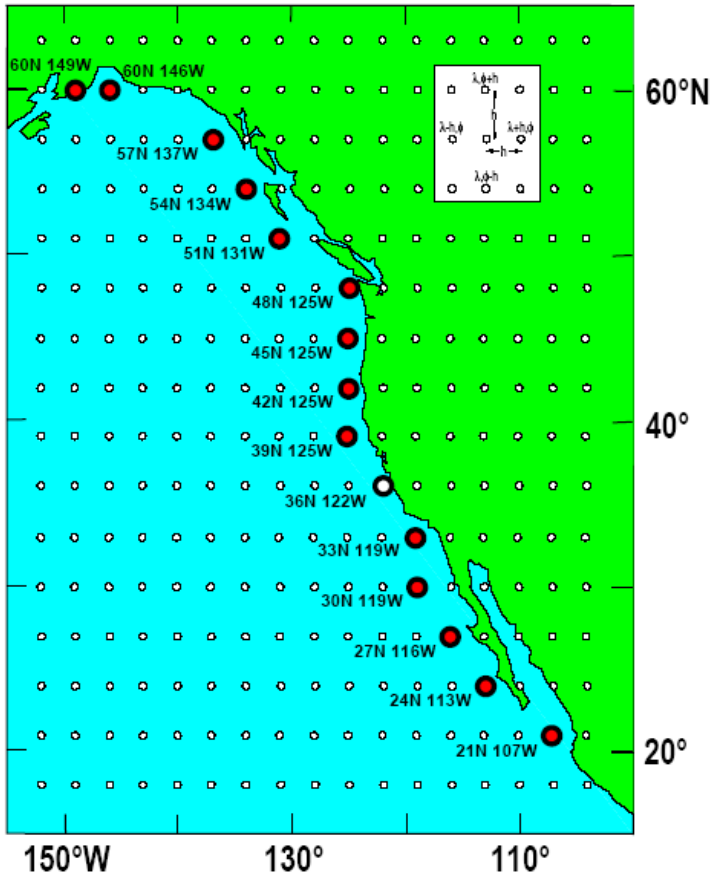
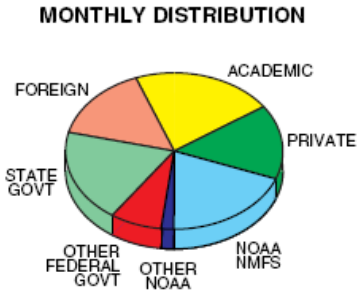


Figure 1. Map showing 3° extrapolated mesh (small open circles) for pressure fields used to derive the upwelling indices. Large open circles denote locations of the 15 standard near-coastal positions of the indices reported here. Inset shows discretization scheme used to estimate geostrophic winds from pressure gradients (Equations 1 and 2).

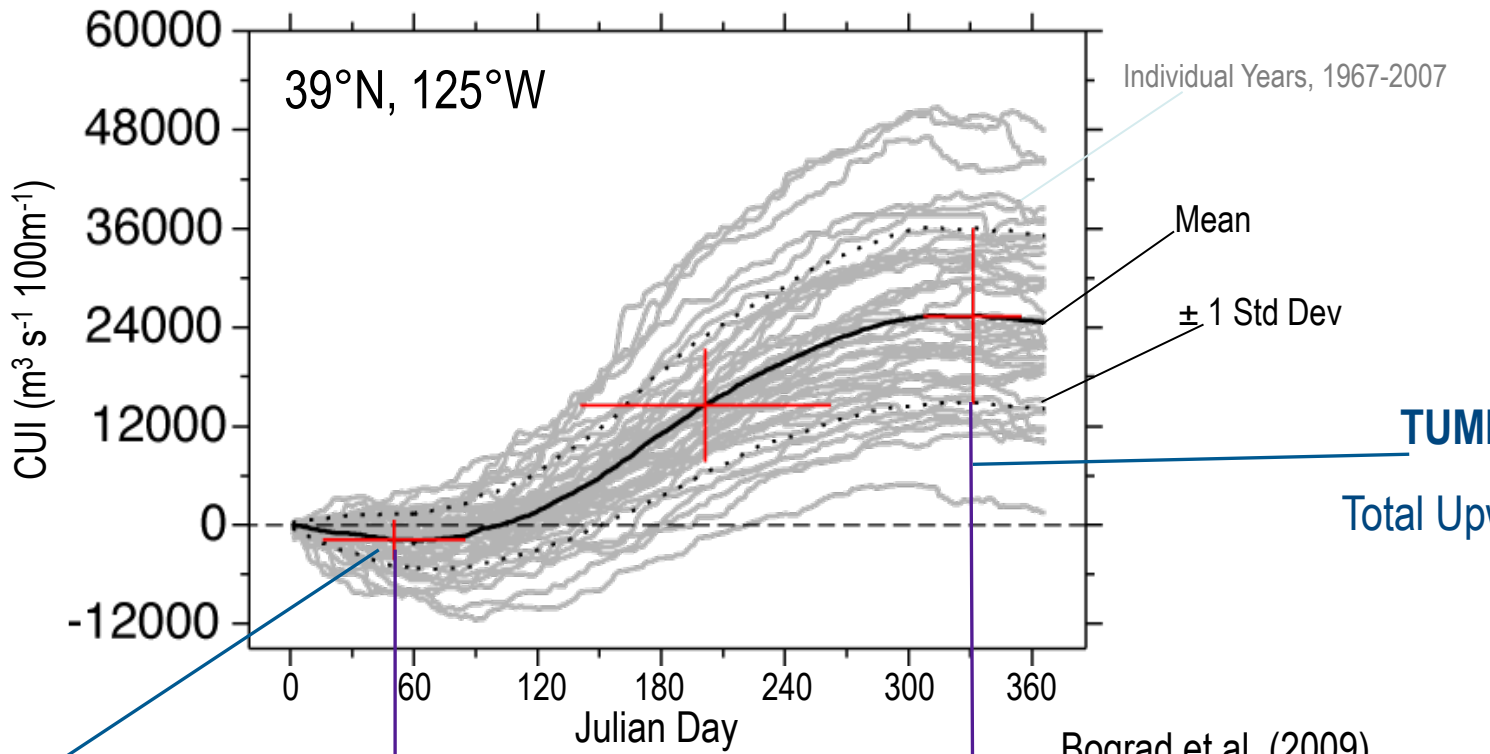
Bakun, A. (1975). Daily and weekly upwelling indices, West Coast of North America, 1967-1973. *NOAA Tech. Rep., NMFS SSRF 693*, 114 pp.

Schwing, F. et al. (1996). Coastal upwelling indices, West Coast of North America, 1946-1995. *NOAA Tech. Mem., NMFS-SWFSC 231*, 32 pp.

> 1000 citations



Interannual Variability in Upwelling Phenology



$$TUMI = \sum_{STI}^{END} CUI(t)$$

Total Upwelling Magnitude

Spring Transition Index (STI)

LUSI

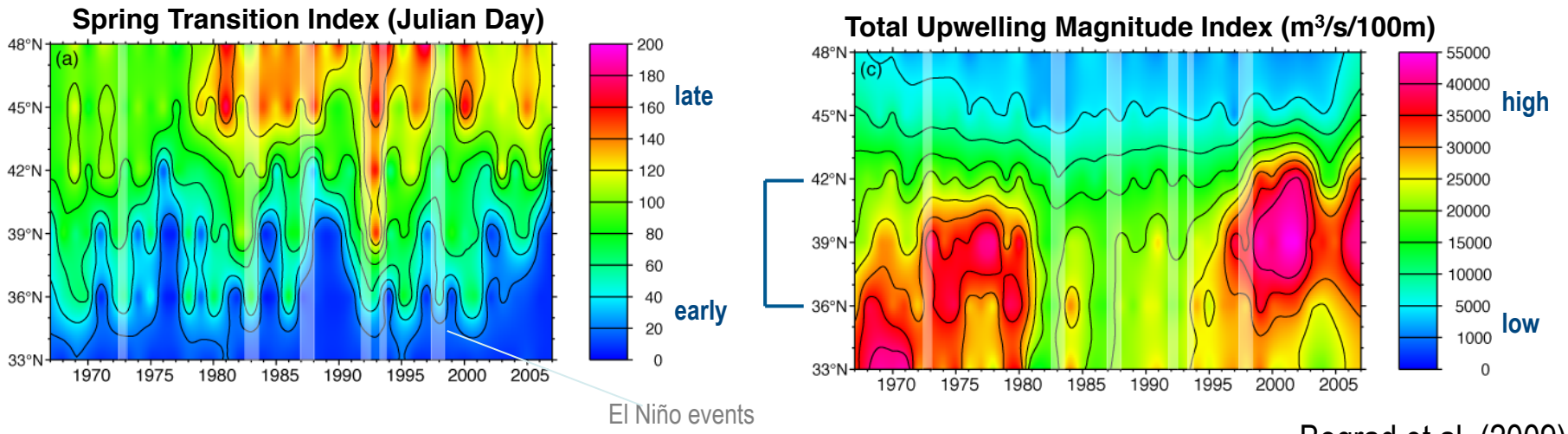
Length of Upwelling Season

STI = Julian Day 50 ± 34

END = Julian Day 331 ± 24

LUSI = 282 ± 45 days

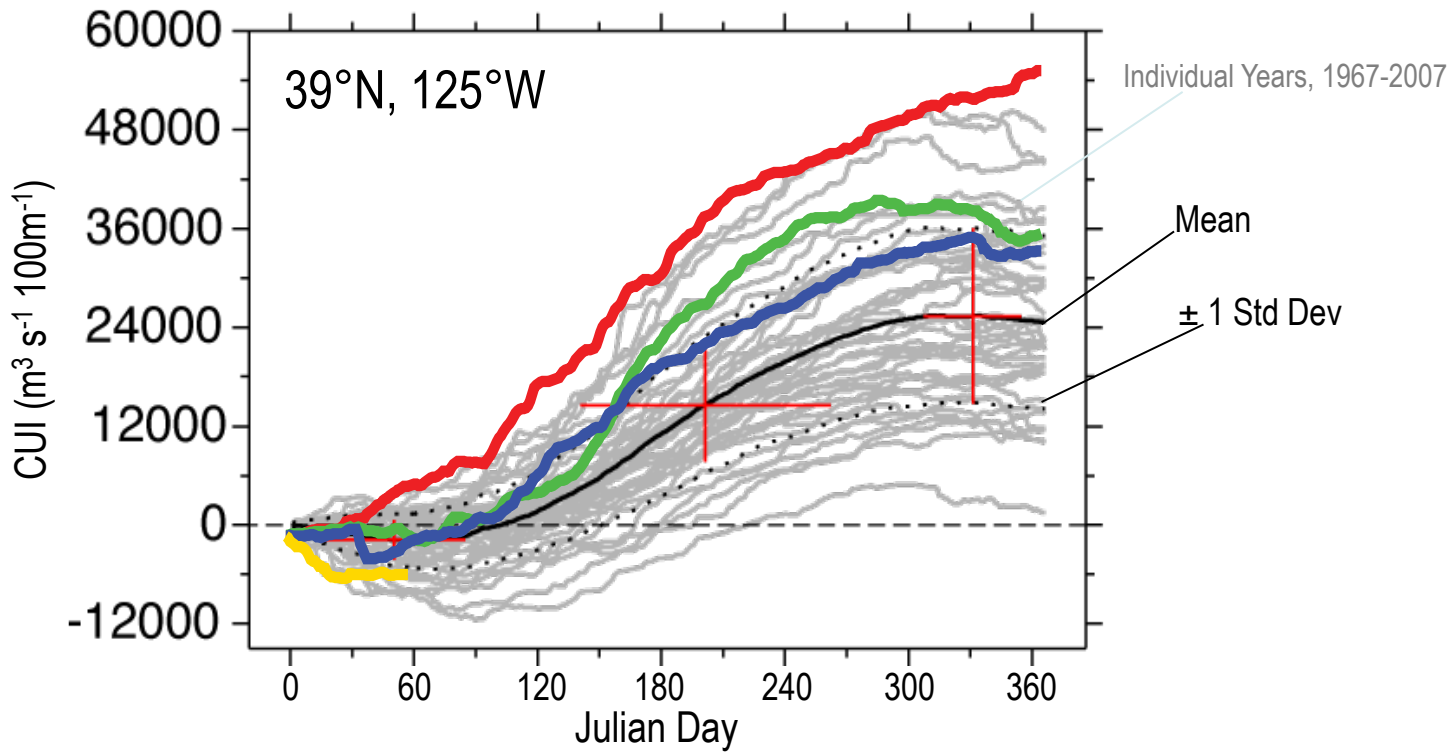
Interannual Variability in Upwelling Phenology



Bograd et al. (2009)

- Earlier onset of upwelling in southern California Current
- Delayed upwelling during El Niño events
- Upwelling 'surplus' or 'deficit' at climatological spring transition date
- Periods of high (1970s, 1998-2004) and low (1980-1995) integrated upwelling

Interannual Variability in Upwelling Phenology



2013

2014

2015

2016

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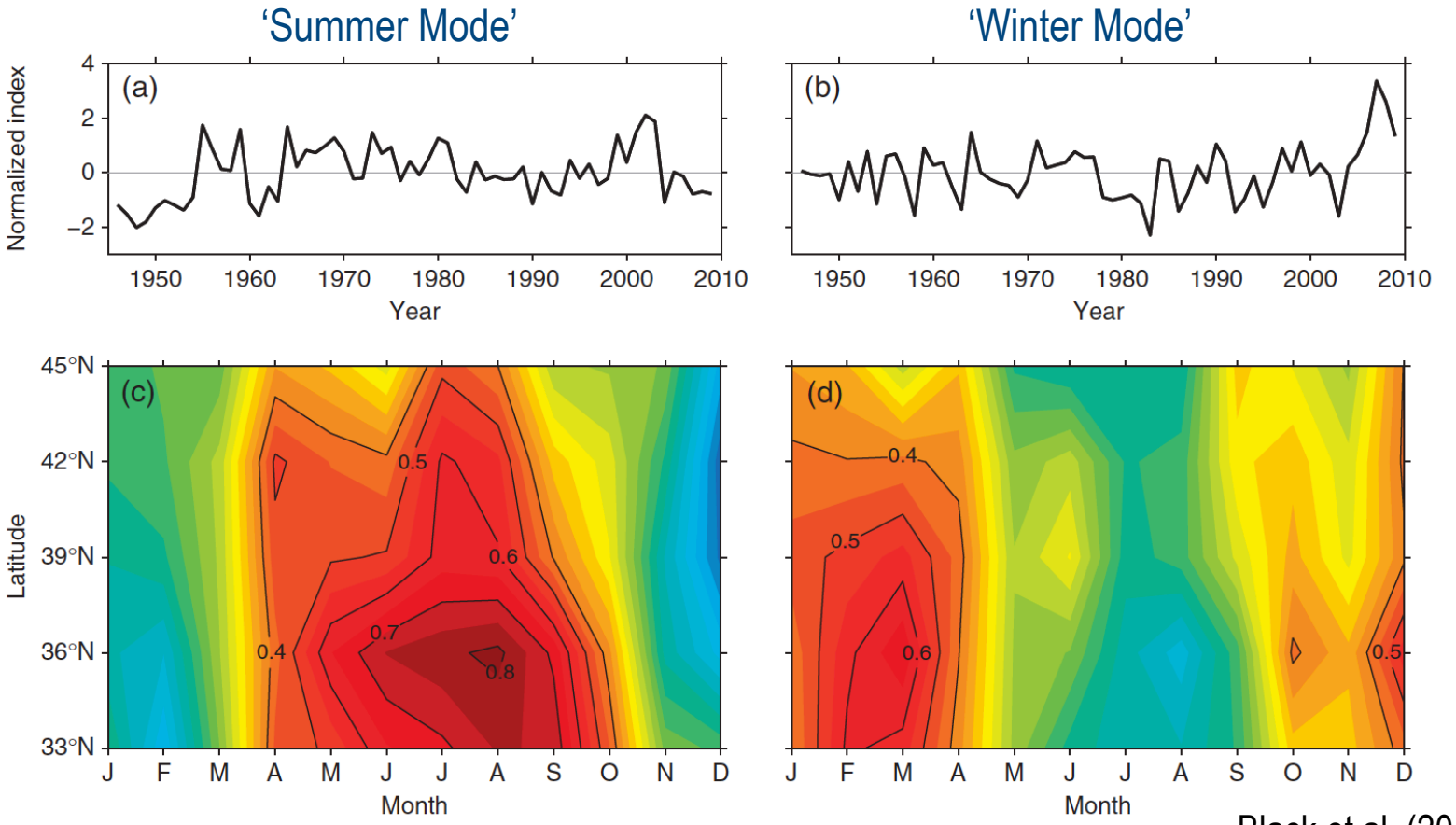
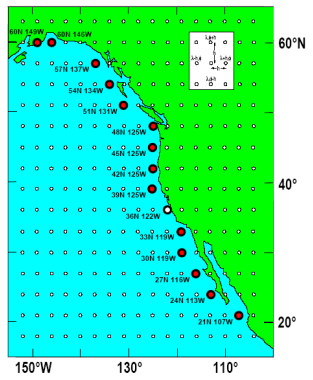
MODES OF UPWELLING VARIABILITY IN THE CCLME

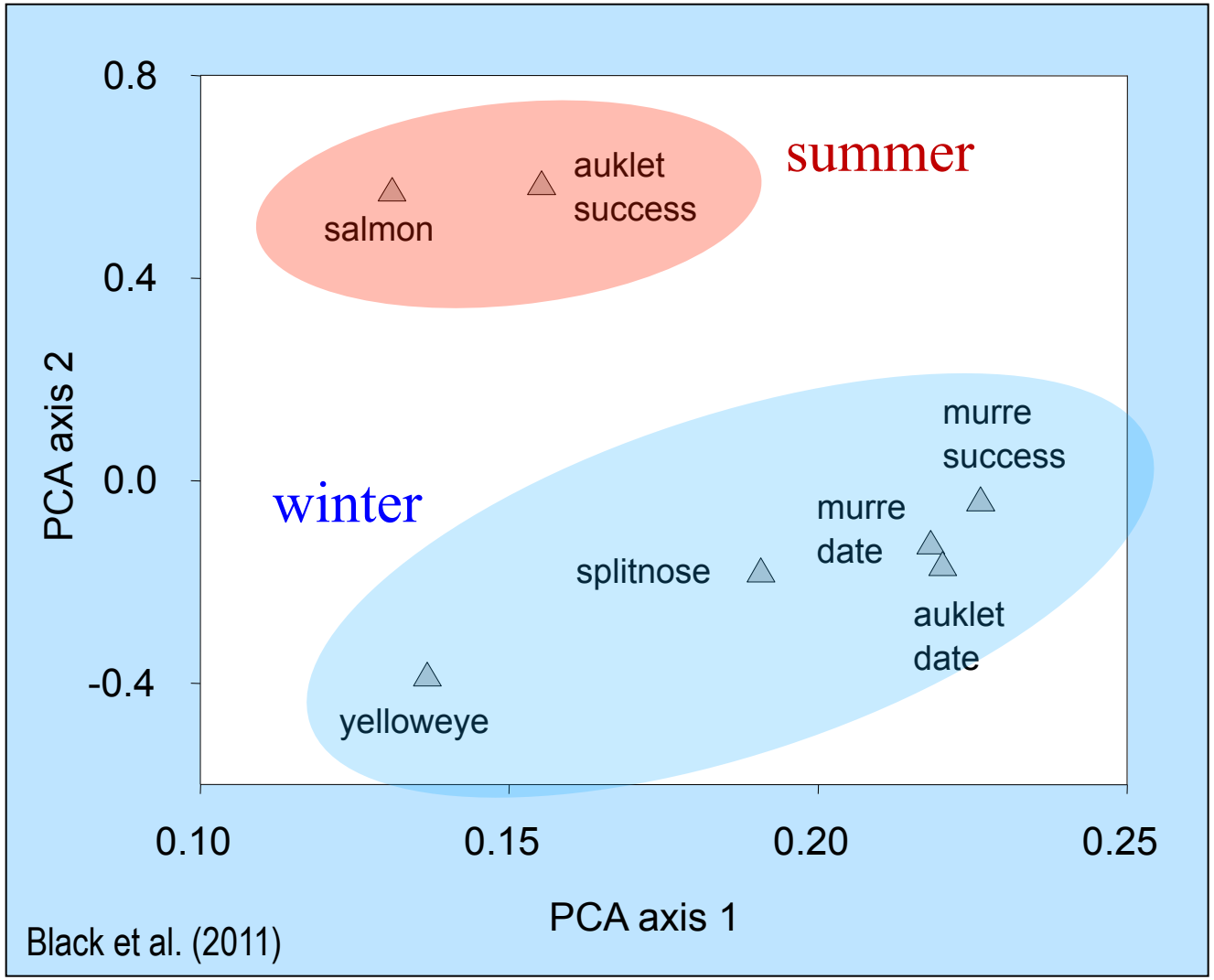


Black et al. (2011)

- First two principal components of Upwelling Index in CC
- PC1: mid-season (spring-summer) upwelling [SUMMER MODE]
- PC2: late winter upwelling [WINTER MODE]
- Ecosystem components have different sensitivities to these two modes of upwelling

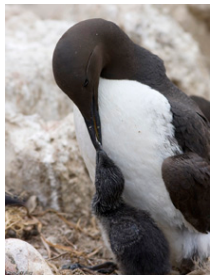


Modes of Upwelling Variability in the CCLME



summer sensitive

winter sensitive

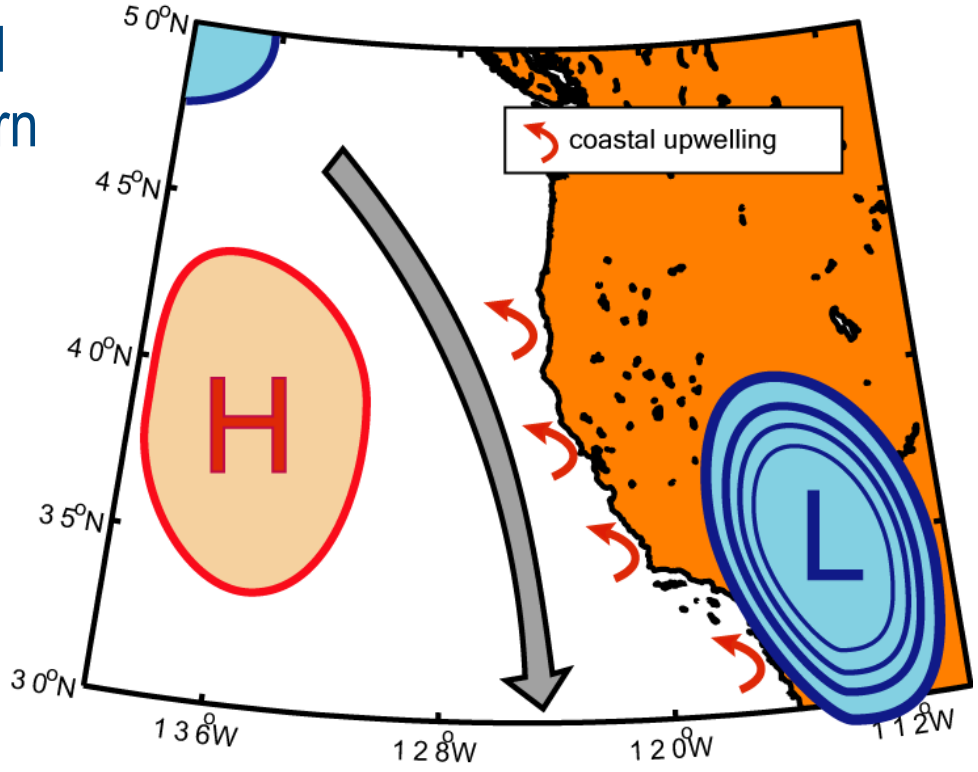


Climate Change and Coastal Upwelling

Bakun (1990) suggested that global warming would enhance summertime upwelling winds in the Eastern Boundary Current Systems

Differential heating of the surface air over the landmass relative to the ocean …

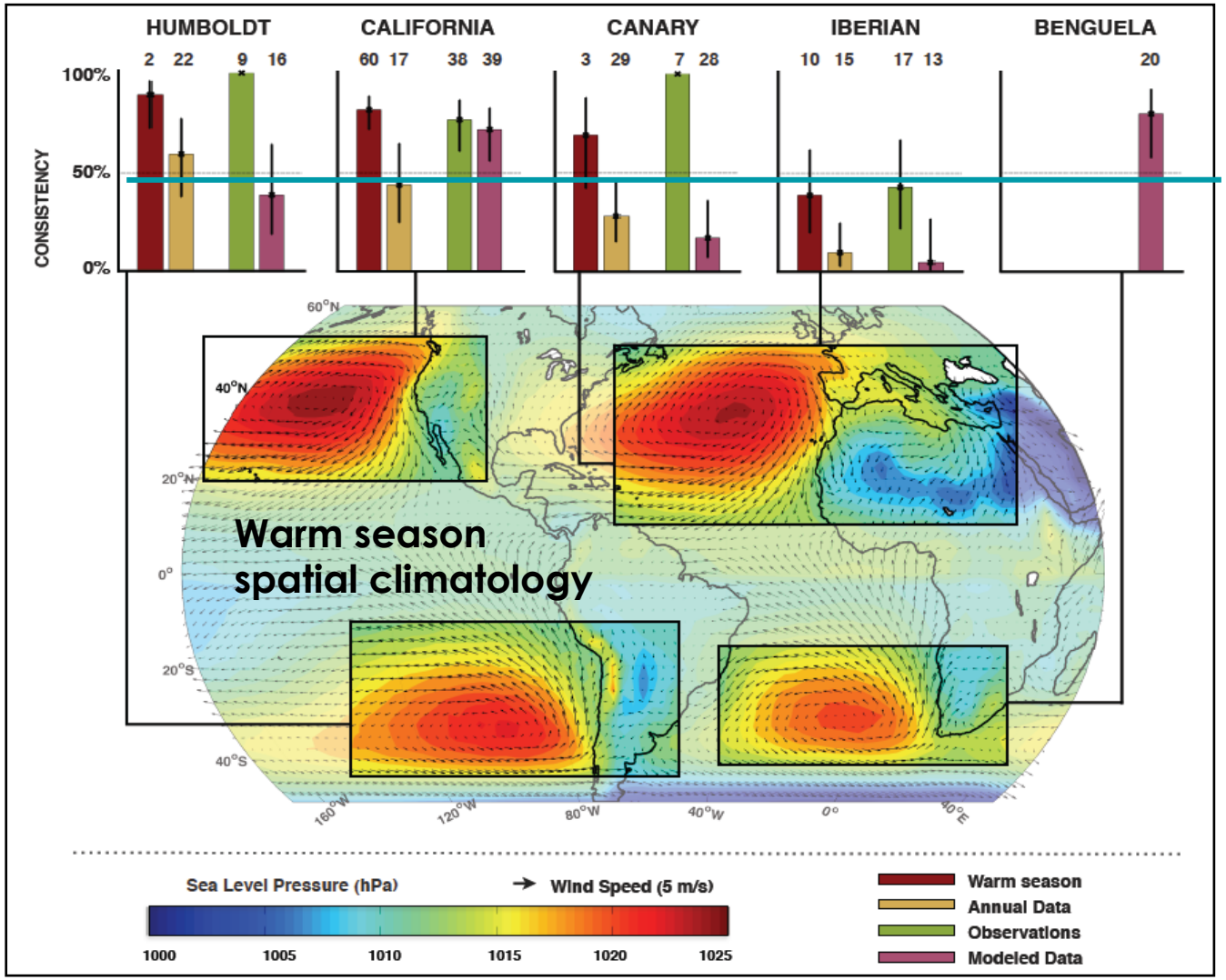
... will result in intensification of the thermal Low over the Southwest, generating a stronger pressure gradient



R. Rykaczewski

CHANGES IN UPWELLING ECOSYSTEMS: *HISTORICAL OBSERVATIONS*

- Meta-Analysis of 22 studies
- 150 time series, various periods between 1950-2010
- All four Eastern Boundary Currents
- Test for consistency with Bakun Hypothesis

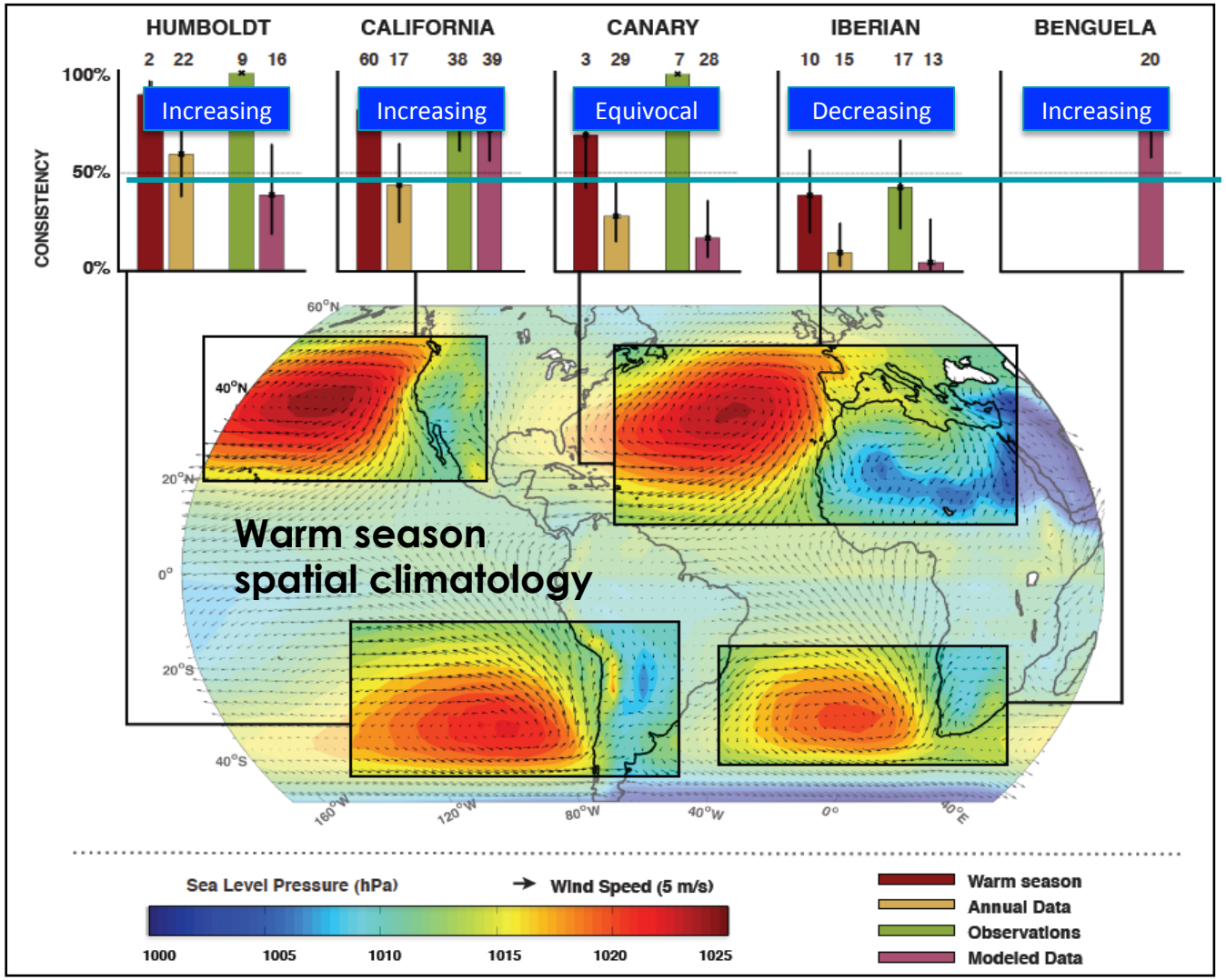


Sydeman et al. (2014)

CHANGES IN UPWELLING ECOSYSTEMS: *HISTORICAL OBSERVATIONS*

- Meta-Analysis of 22 studies
- 150 time series, various periods between 1950-2010
- All four Eastern Boundary Currents
- Test for consistency with Bakun Hypothesis

- Evidence of upwelling intensification in 3/5 EBCs
- Dependent on: season, time period, latitude, data type



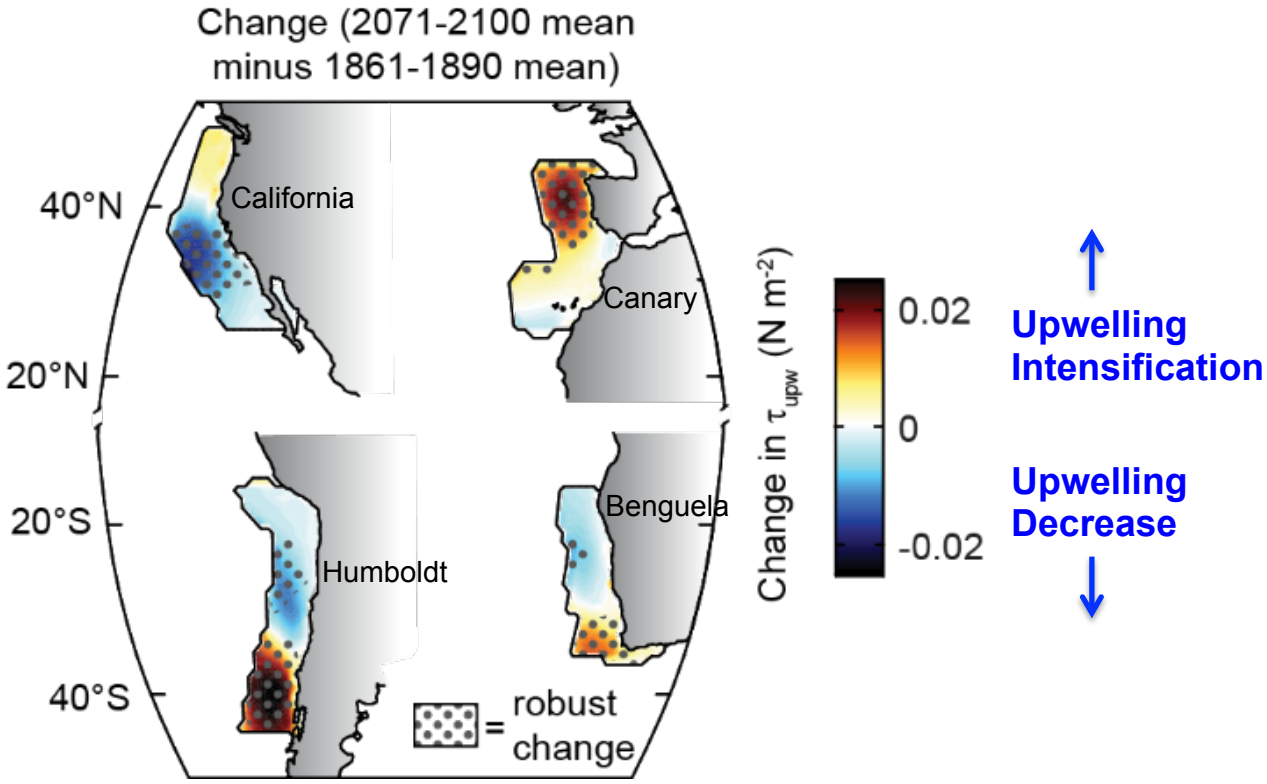
Increase

Decrease

Sydeman et al. (2014)

CHANGES IN UPWELLING ECOSYSTEMS: *FUTURE PROJECTIONS*

- IPCC AR5 models that capture historical conditions (1850-2005)
- Surface air temperature, sea level pressure, surface wind stress at monthly resolution
- Simulations from 2006-2100 using RCP 8.5



Rykaczewski et al. (2015)

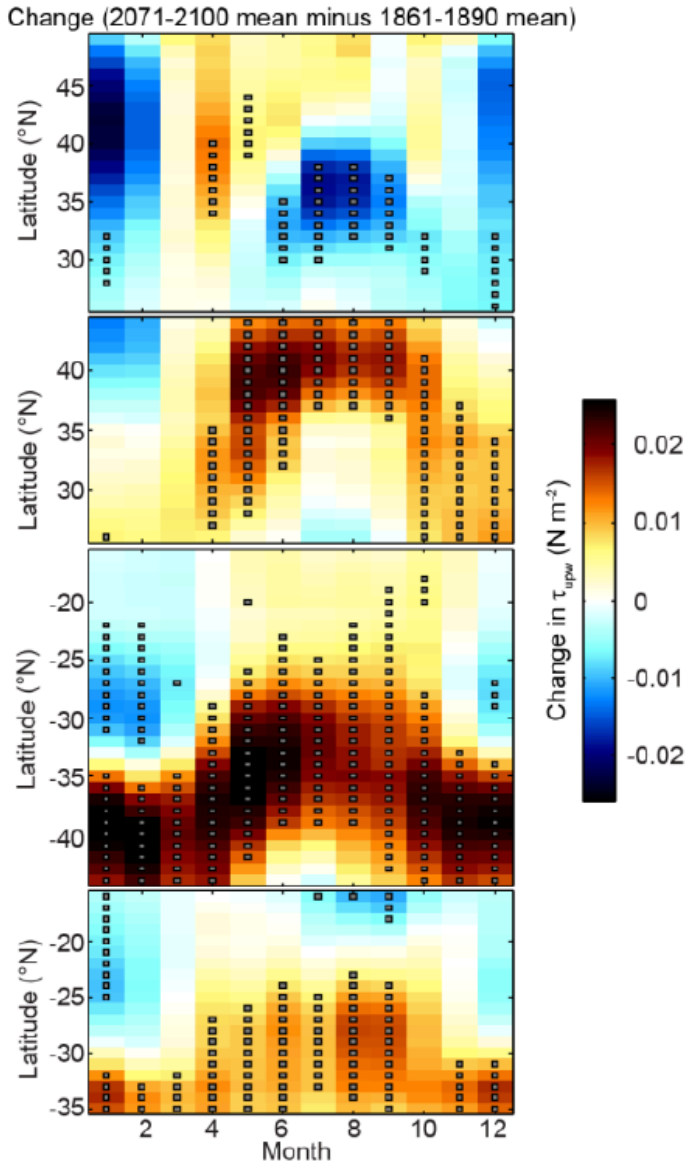
CHANGES IN UPWELLING ECOSYSTEMS: *FUTURE PROJECTIONS*

California

Canary

Humboldt

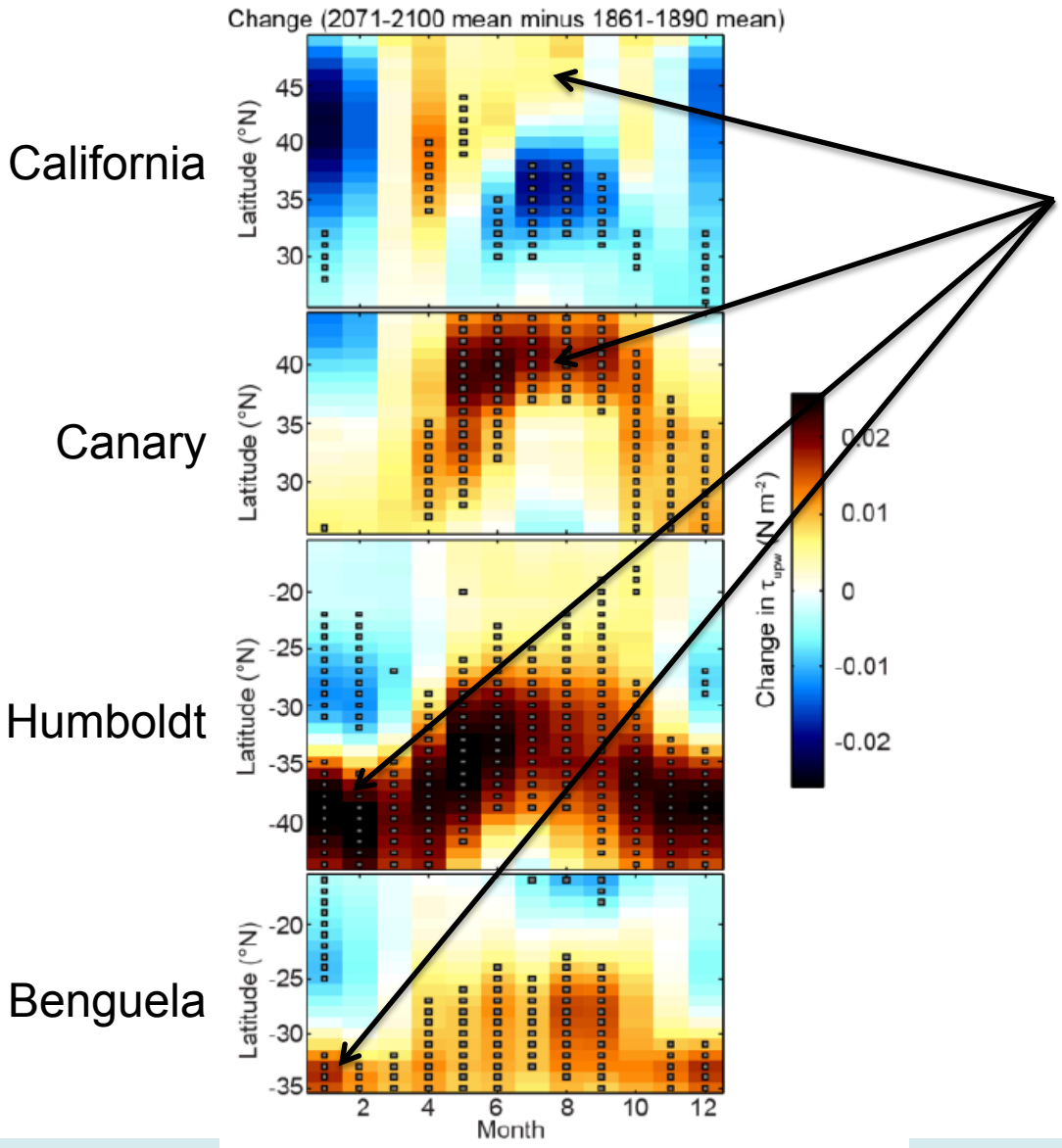
Benguela



ΔUpwelling by month and latitude

Rykaczewski et al. (2015)

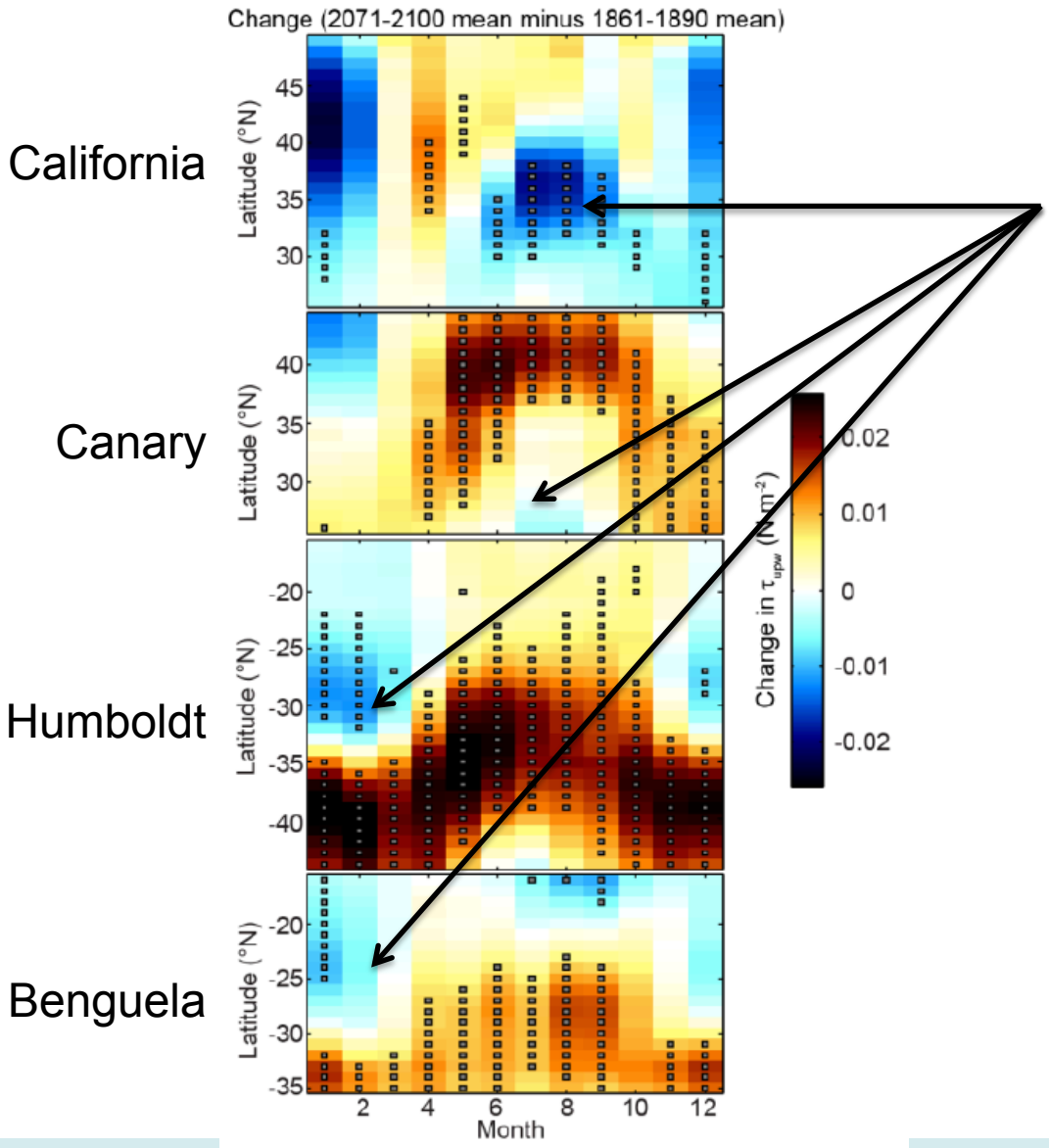
CHANGES IN UPWELLING ECOSYSTEMS: *FUTURE PROJECTIONS*



Increased summer upwelling in poleward regions

Rykaczewski et al. (2015)

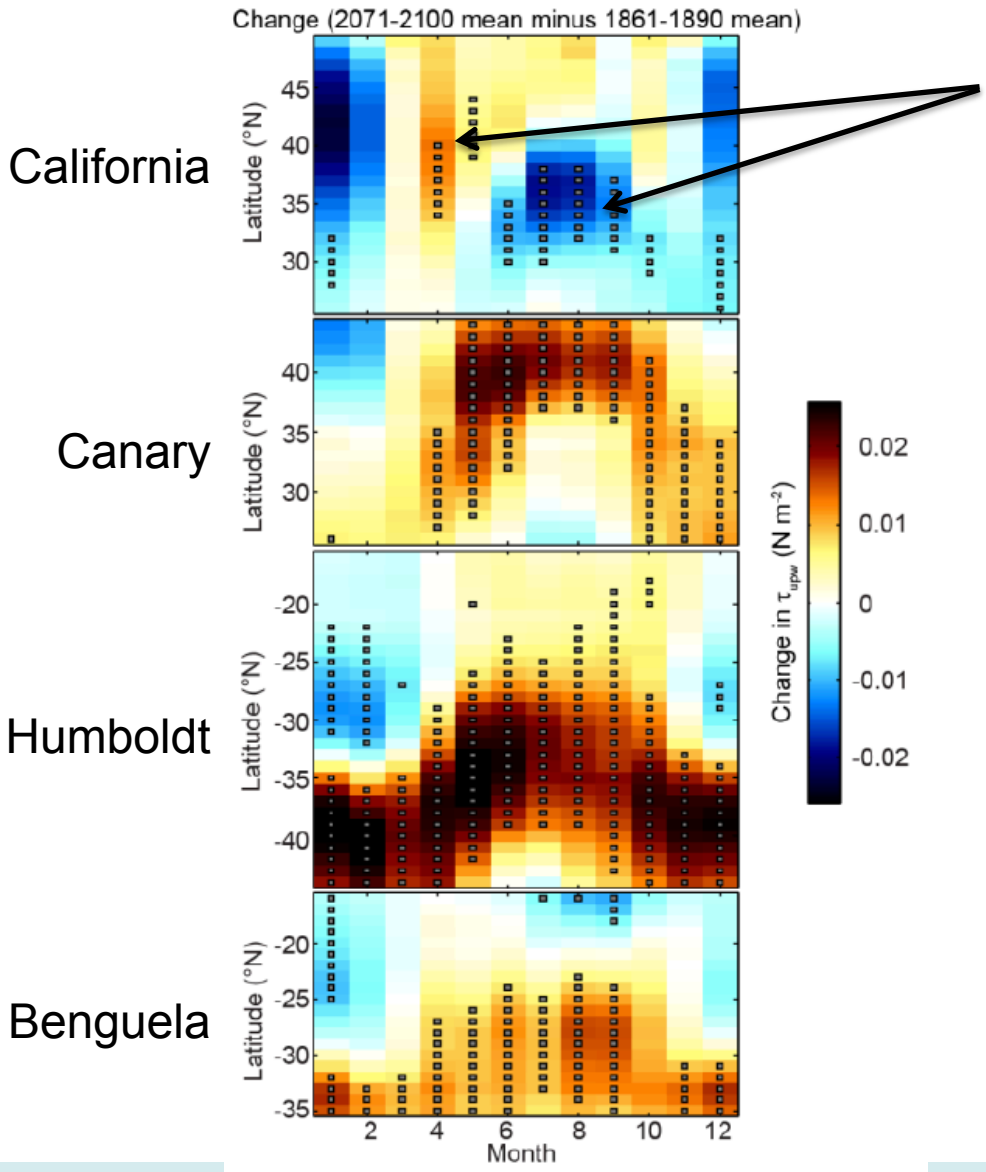
CHANGES IN UPWELLING ECOSYSTEMS: *FUTURE PROJECTIONS*



Decreased summer upwelling in equatorward regions

Rykaczewski et al. (2015)

CHANGES IN UPWELLING ECOSYSTEMS: *FUTURE PROJECTIONS*



Enhanced ‘Winter Mode’

Weakened ‘Summer Mode’

Rykaczewski et al. (2015)

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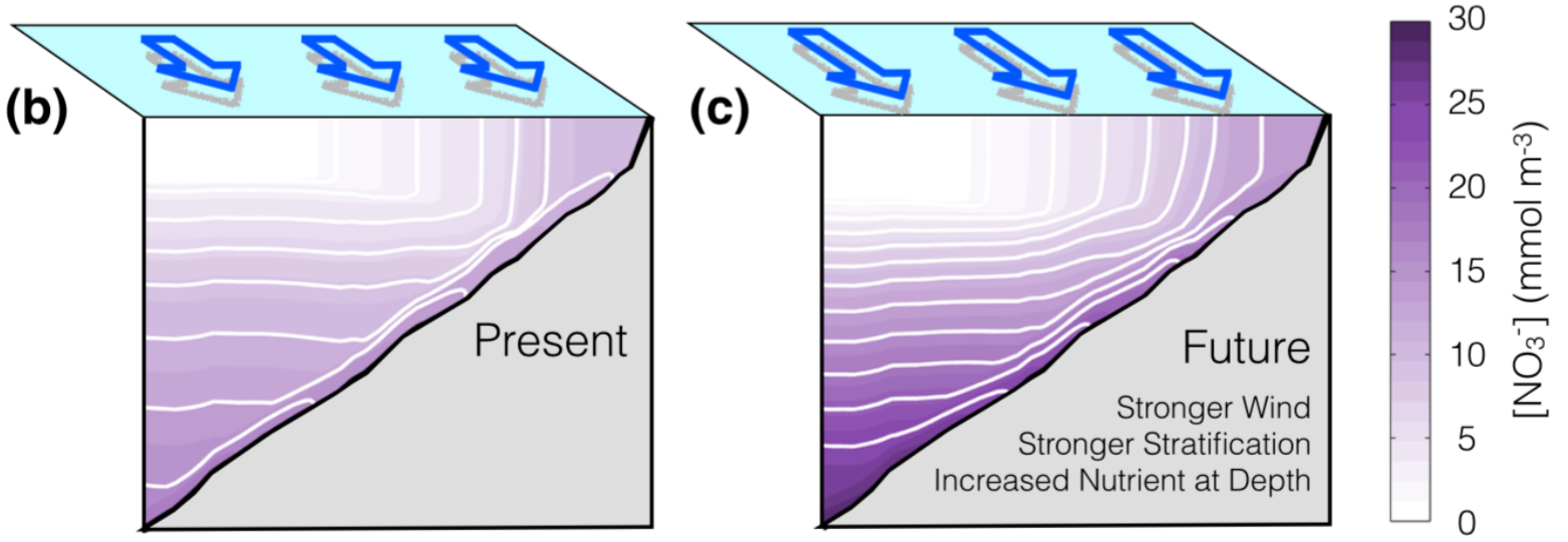
CLIMATE IMPACTS ON THE CCLME

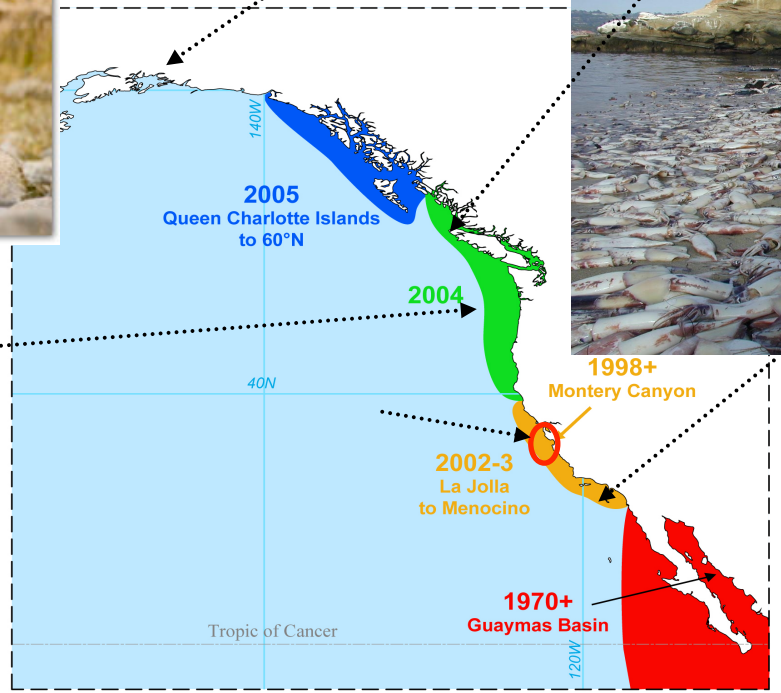


Jacox et al. (2015)

- Changes in stratification …?
- Changes in nutrient content of source waters …?
- Increased hypoxia and ocean acidification …?
- Plasticity of species dependent on coastal upwelling …?

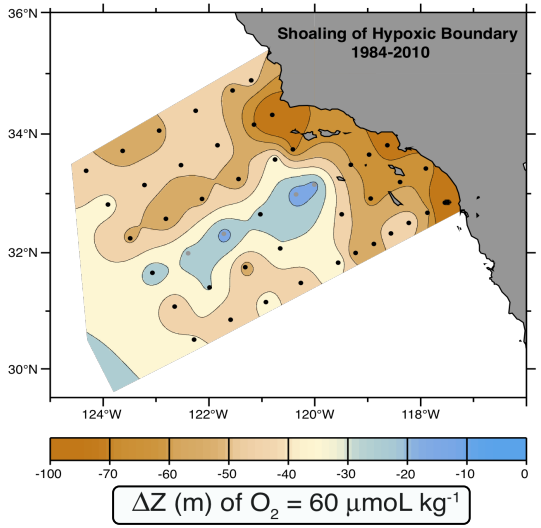
Ecosystem Impacts of Changing Biogeochemistry

Wayne Barnes/ Tofino Photography



Range expansion of Humboldt squid following 1997-98 El Niño and declining oxygen levels

Bograd et al. (2008)
Stewart et al. (2012)
Stewart et al. (2014)



Brown Pelican

years, until 2009. Now, their future is uncertain once again.

Climate-Ecosystem Research: Strengths, Challenges and Strategies

- Strengths
  - Long history of coastal upwelling research (birthplace of the 'Upwelling Index')
  - Development & dissemination of environmental data products
  - Strong collaborations with NOAA (OAR-ESRL, GFDL), academic & international partners
  - Upwelling research provides mechanistic foundation for EBFM
- Challenges
  - Some deficiencies in classical indices and relating to ecosystem impacts
  - Spatial and temporal gaps in key ocean observations
  - Need regional downscaling & short-term to mid-term forecasting capacity
- Strategies
  - Continued broad & productive collaborations
  - Improved modeling capacity (including biogeochemistry) for hypothesis testing
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Questions?